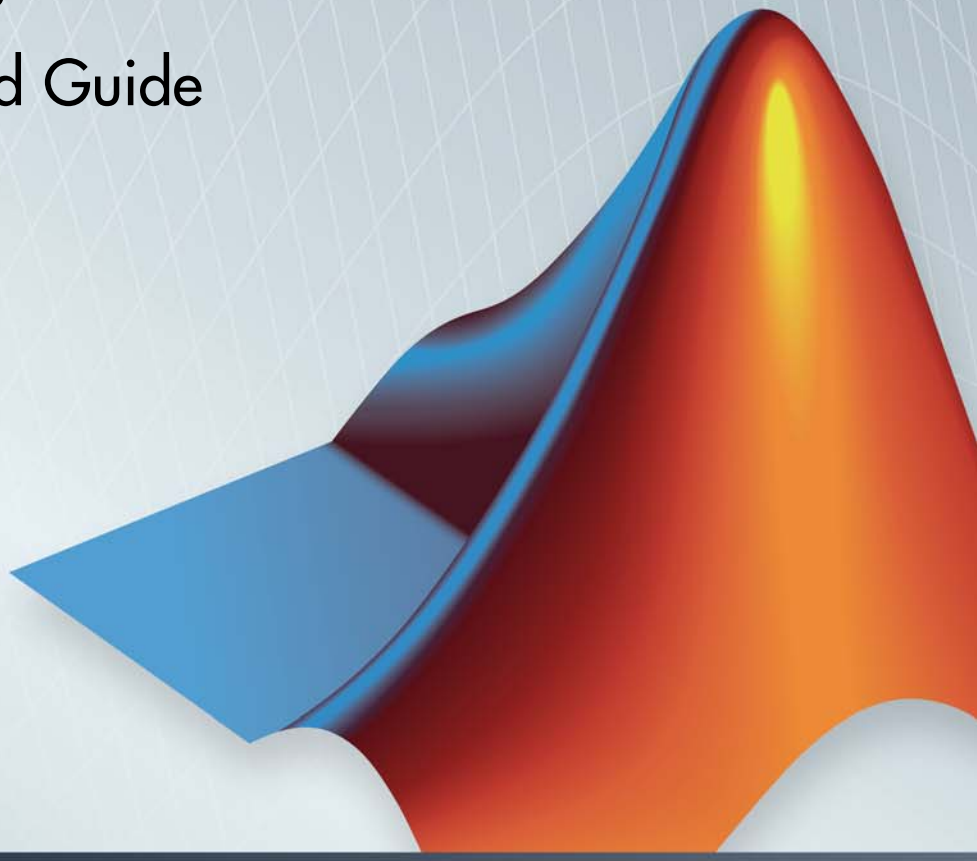
SimMechanics™

Getting Started Guide

R2014**a**



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SimMechanics™ Getting Started Guide

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Introduction to SimMechanics Software

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SimMechanics Product Description

Model and simulate multibody mechanical systems

SimMechanics™ provides a multibody simulation environment for 3D mechanical systems, such as robots, vehicle suspensions, construction equipment, and aircraft landing gear. You model the multibody system using blocks representing bodies, joints, constraints, and force elements, and then SimMechanics formulates and solves the equations of motion for the complete mechanical system. Models from CAD systems, including mass, inertia, joint, constraint, and 3D geometry, can be imported into SimMechanics. An automatically generated 3D animation lets you visualize the system dynamics.

You can parameterize your models using MATLAB® variables and expressions, and design control systems for your multibody system in Simulink®. You can add electrical, hydraulic, pneumatic, and other components to your mechanical model using Simscape™ and test them all in a single simulation environment. To deploy your models to other simulation environments, including hardware-in-the-loop (HIL) systems, SimMechanics supports C-code generation (with Simulink Coder™).

Key Features

- Blocks and modeling constructs for simulating and analyzing 3D mechanical systems in Simulink
- Rigid body definition using standard geometry and custom extrusions defined in MATLAB
- Automatic calculation of mass and inertia tensor
- Simulation modes for analyzing motion and calculating forces
- Visualization and animation of multibody system dynamics with 3D geometry
- SimMechanics Link utility, providing an interface to Pro/ENGINEER®, SolidWorks®, and Autodesk Inventor, and an API for interfacing with other CAD platforms
- Support for C-code generation (with Simulink Coder)

Required and Related Products

In this section...
"SimMechanics Visualization Requirements" on page 1-3
"Support for Recorded Animations" on page 1-3
"Related Products" on page 1-3

SimMechanics Visualization Requirements

SimMechanics visualization requires Silicon Graphics OpenGL® graphics support on your system to display and animate SimMechanics models.

You can improve your speed and graphics resolution by adding a graphics accelerator hardware card to your system. Animation of simulations is sensitive to central processor and graphics card speed and memory. Experiment with graphics hardware and system settings to find a reasonable compromise between quality and speed for your system.

Support for Recorded Animations

You can record simulation animations in Microsoft Audio Video Interleave® (AVI) format using SimMechanics visualization. Animations are recorded as compressed AVI files with the default Motion JPEG codec. This codec is available on most operating systems.

To play back AVI files, you need an AVI-compatible media application. MATLAB has an internal movie player compatible with AVI. You can also use an external AVI-compatible player.

Note SimMechanics visualization does not support uncompressed AVI recording.

Related Products

You can extend the capability of SimMechanics using other physical modeling products found in the Simscape family. Each physical modeling product gives

you a set of block libraries with which you can model common components found in industry and academia: rigid bodies, gears, valves, solenoids, etc.

With the physical modeling products, you can model not only mechanical systems, but also electrical, hydraulic, and power systems. You can model each system separately, and then integrate the systems into a single multiphysics model where you can analyze combined system performance.

Physical Modeling Product Family

The physical modeling family includes five products:

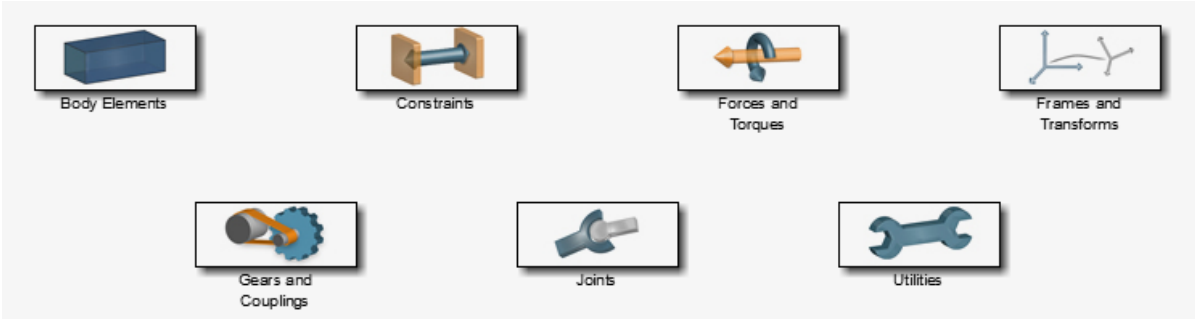
- SimDriveline™, for modeling and simulating drivetrain systems
- SimElectronics®, for modeling and simulating electronic systems
- SimHydraulics®, for modeling and simulating hydraulic systems
- SimMechanics, for modeling and simulating three-dimensional mechanical systems
- SimPowerSystems™, for modeling and simulating electrical power systems

Representing Machines with SimMechanics Blocks

To model a 3-D multibody system, you use the SimMechanics block library. This library contains seven sublibraries that you represent the different model components with. Components that you can represent include rigid bodies, joints, gear and general kinematic constraints, forces and torques, and motion sensors.

Open the Library

To open the SimMechanics block library, at the MATLAB command line enter `sm_lib`. The SimMechanics block library opens in a new window. The figure shows the library.



SimMechanics™ Block Library

Explore the Library

The table summarizes the modeling purpose of each SimMechanics sublibrary. Open a sublibrary to explore its blocks. For detailed information about a block, see its reference page. You can do this by double-clicking the block and clicking **Help** in the block dialog box.

Sublibrary	Description
Body Elements	Represent the solid properties of a rigid body
Constraints	Constrain the relative motion between two rigid body frames

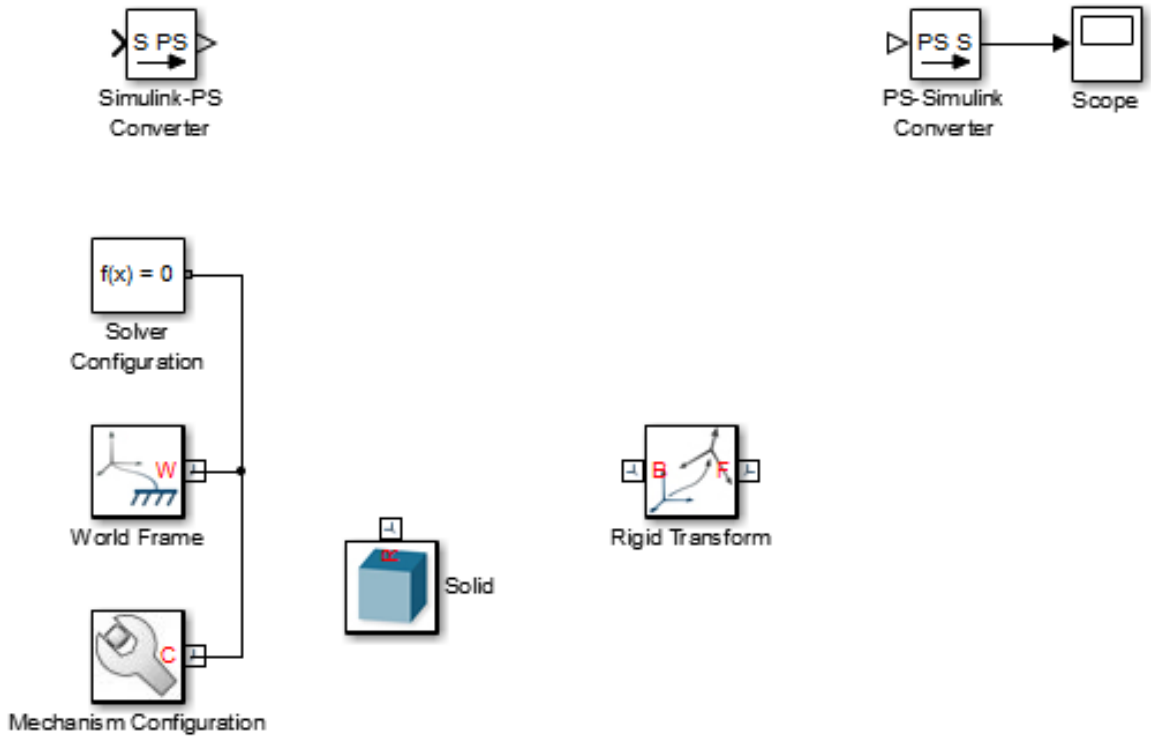
Sublibrary	Description
Forces and Torques	Apply internal and external forces and torques on or between rigid body frames
Gears and Couplings	Couple the motion of two rigid body frames
Joints	Represent the mechanical degrees of freedom between two rigid body frames
Utilities	Represent the mechanical environment of a multibody system

Related Examples

- "Start New Multibody Model" on page 1-7

Start New Multibody Model

You can start a new multibody model from the MATLAB command line. To do this, enter `smnew`. A new model window opens with commonly used blocks. The SimMechanics block library also opens. The figure shows the new model window that you see. Drag blocks from the library into the model window to begin modeling a new multibody system.



Concepts

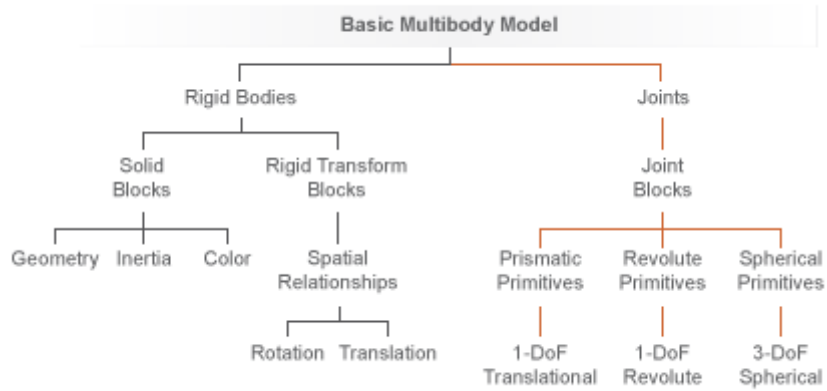
- “Representing Machines with SimMechanics Blocks” on page 1-5

Multibody Model Anatomy

In this section...
“Basic Model Components” on page 1-9
“Model Actuation” on page 1-11
“Dynamical Sensing” on page 1-14

With SimMechanics, you represent a multibody system using blocks. Like all physical modeling products, each block represents a physical component or an abstract entity fundamental to physical modeling, e.g. frames and frame transforms.

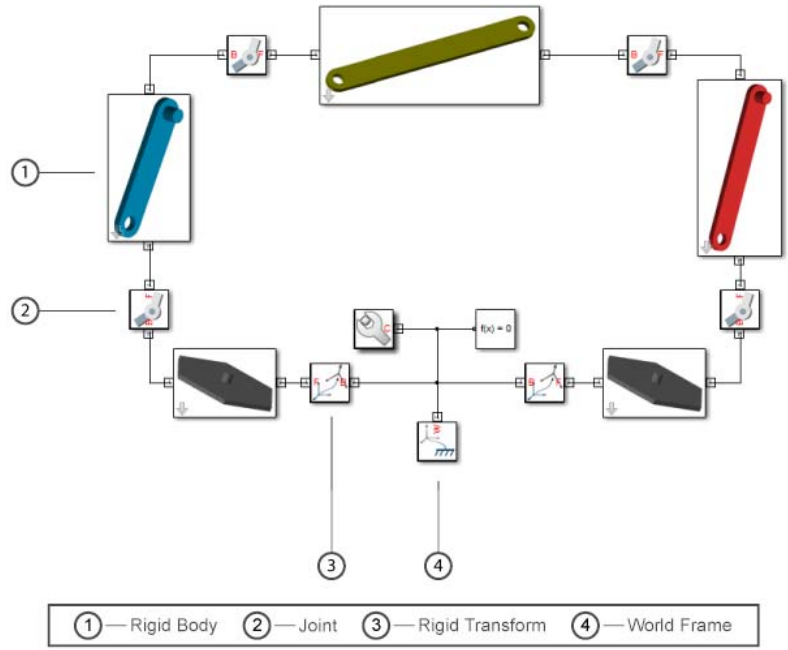
By connecting the blocks with connection lines, you define the relationships that unite the physical components into a single system (or subsystem). In a basic model, these physical components include rigid bodies and joints. You can also add forces and torques, motion sensors, and kinematic constraints, e.g., to represent gears.



Basic Structure of a Multibody Model

Basic Model Components

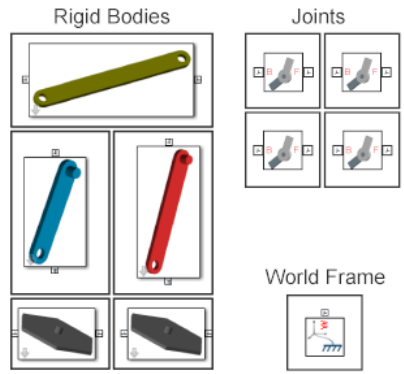
The figure shows the block diagram of a multibody system—the four-bar linkage. This model contains subsystem blocks to represent the links and pivot mounts. These represent the rigid bodies of the model. The model contains also four Revolute Joint blocks. These represent the joints in the model. Combined, these blocks form the foundation of this model.



While important, rigid body subsystem and joint blocks are not sufficient to represent the four-bar linkage. Other blocks serve important purposes. These include World Frame, Rigid Transform, Mechanism Configuration, and Solver Configuration blocks. The table summarizes their functions in a multibody model.

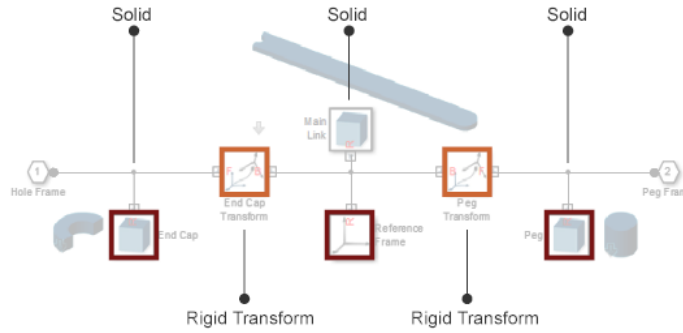
Block	Function
World Frame	Provides the ultimate reference frame in a model. All remaining frames are defined with respect to this frame. It is inertial and it defines absolute rest.
Rigid Transform	Applies a fixed spatial relationship between frames. This block defines the offset distance and angle between two frames.
Mechanism Configuration	Identifies the gravity vector in a model.
Solver Configuration	Provides essential simulation parameters required to simulate the model.

The figure breaks the four-bar model into its logical components. These are the physical components and abstract entities that you need in order to represent this system.



Each rigid body subsystem contains SimMechanics blocks that represent solids and their spatial relationships. The blocks are Solid and Rigid Transform. The figure shows the blocks that model one of the binary links. Three Solid blocks represent the three solid sections of this rigid body—main, peg, and hole sections. Two Rigid Transform blocks represent the fixed spatial

relationships between the three solids. You use them to position the peg and hole sections at the ends of the main section.



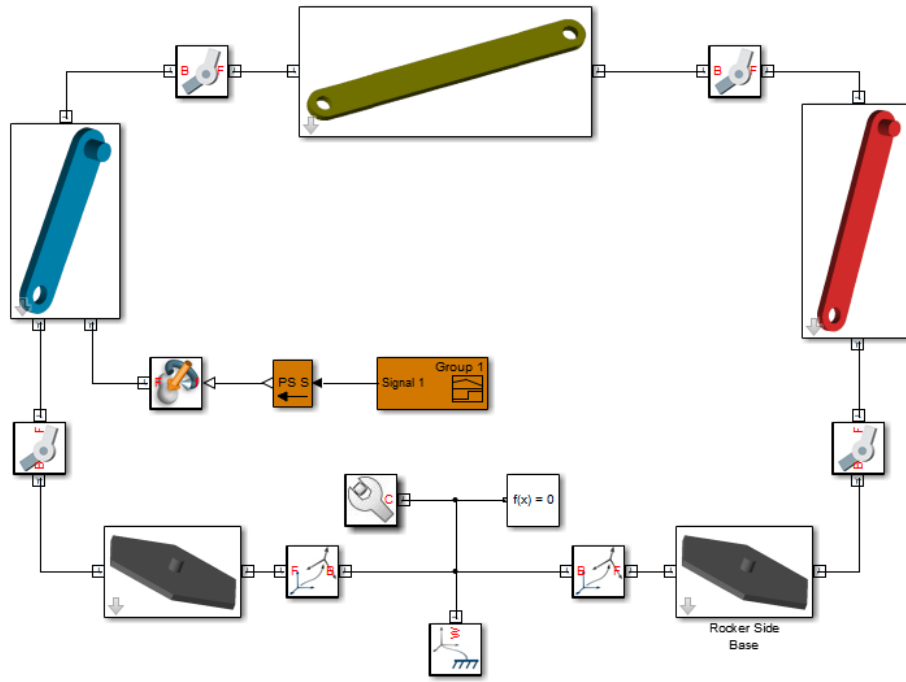
Model Actuation

You can actuate a model by applying a force or torque to a rigid body or to a joint. To represent forces and torques acting on a rigid body, SimMechanics provides a Forces and Torques library. Drag a block from this library and connect it to the rigid body frame(s) that you want to apply the force or torque to.

Block	Function
External Force and Torque	General force and/or torque originating outside of the multibody model
Internal Force	General force pair between two arbitrary frames
Spring and Damper Force	Spring-damper force pair between two arbitrary frames

Block	Function
Inverse Square Law Force	Force pair with inverse dependence on the square distance between two arbitrary frames (e.g., Coulomb electrostatic forces)
Gravitational Field	Gravitational pull of a point mass on all rigid bodies as a function of their distances to the point mass itself

The figure shows a four-bar model with an External Force and Torque block for force and torque prescription at a crank link frame.



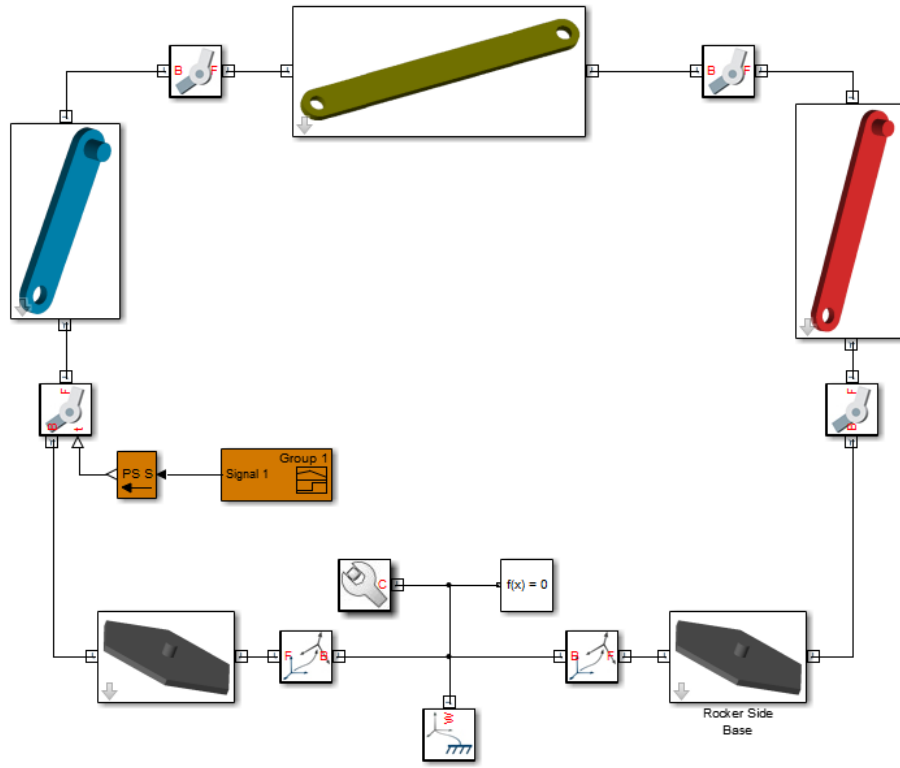
To specify the force or torque acting at a joint, SimMechanics provides a selection of actuation inputs directly in the joint blocks. Each joint

primitive—the basic component of a joint block—provides a selection of actuation inputs specific to that primitive.

Joint actuation inputs can be of two types:

- Motion — Specify the time-varying trajectory of a given joint primitive.
- Force or torque — Specify the time-varying actuation force or torque acting at a given joint primitive.

The figure shows a four-bar model with an actuation torque acting at a revolute joint.



Dynamical Sensing

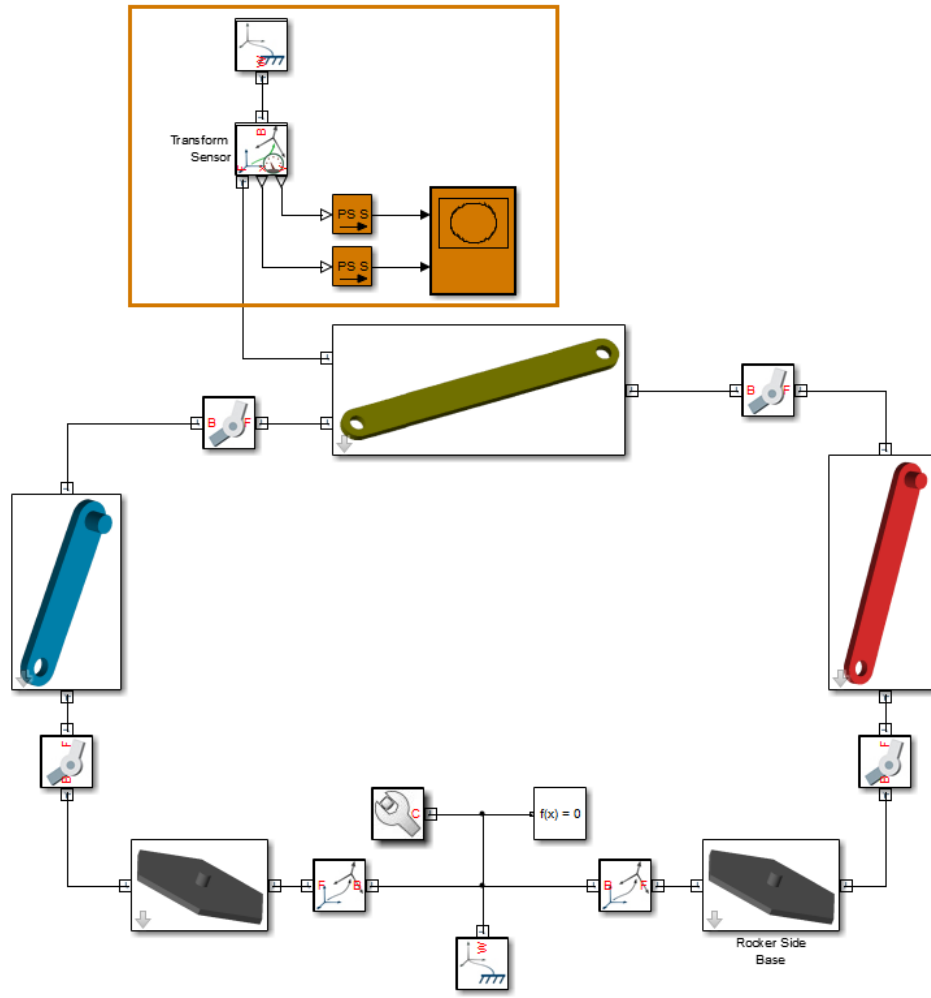
You can sense various dynamical variables between frame pairs, e.g., for analysis or control design. Sensing outputs can be of two types:

- Motion — Compute and output the relative position, velocity, or acceleration between two SimMechanics frames. You can sense motion between joint frames, by using the sensing capability of joint blocks, or between arbitrary frames, by using the Transform Sensor block.
- Force or torque — Compute and output the forces and torques acting between two SimMechanics frames. You can sense force and torque between the port frames of certain Forces and Torques blocks, such as the Inverse Square Law Force block, or between the port frames of a joint block.

Joint blocks enable you to sense different types of forces and torques between their respective port frames, including:

- Actuation force or torque acting at a given joint primitive.
- Constraint force and torque acting joint-wide to prevent motion normal to the joint degrees of freedom.
- Total force and torque, including constraint and joint primitive actuation contributions, acting joint-wide.

The figure shows a four-bar model with a Transform Sensor block for trajectory coordinate sensing between a coupler link frame and the world frame.



Related Examples

- “Model Simple Link” on page 1-16
- “Model Pendulum” on page 1-21

Model Simple Link

In this section...

"Model Overview" on page 1-16

"Build Model" on page 1-17

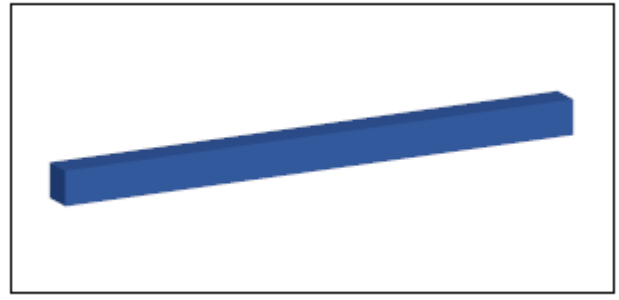
"Generate Subsystem" on page 1-18

"Visualize Model" on page 1-19

"Save Model" on page 1-20

Model Overview

Mechanical links are common building blocks in linkages, mechanisms, and machines. The simple pendulum is an example with one link. In this tutorial, you model a simple link with two end frames that you can later connect to joints. Rigid Transform blocks provide the end frames, while a Solid block provides geometry, inertia, and color. For simplicity, the model assumes the link has a brick shape.

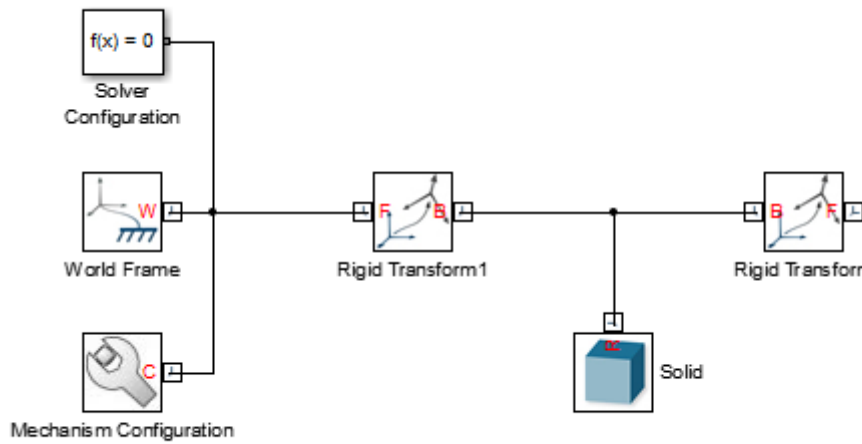


Note Except where noted, all parameters use the default physical units.

Build Model

1. At the MATLAB command line, enter `smnew`. The SimMechanics block library and a new model open up.
2. In the model, copy the Rigid Transform block and paste a copy in the model.
3. Delete these blocks: Simulink-PS Converter, PS-Simulink Converter, and Scope.
4. Connect the blocks as shown in the figure.

Note The base (B) frame ports of both Rigid Transform blocks must face the Solid block.



5. In the dialog box for the Solid block, specify these parameters.

Parameter	Value
Geometry > Dimensions	`[L W H]` (in units of `cm`)
Inertia > Density	`rho`
Graphic > Visual Properties > Color	`rgb`

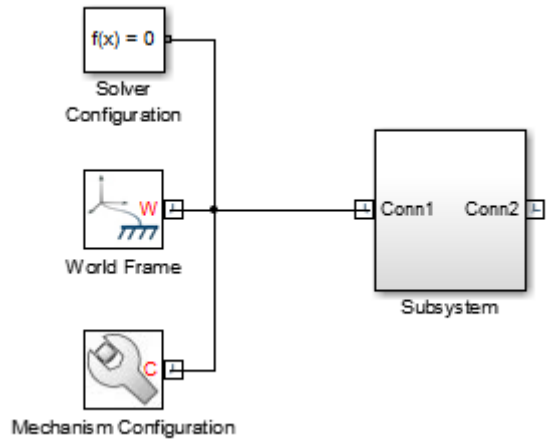
6 In the dialog boxes for the Rigid Transform blocks, specify these parameters.

Parameter	Rigid Transform1	Rigid Transform
Translation > Method	`Standard Axis`	`Standard Axis`
Translation > Axis	`-X`	`+X`
Translation > Offset	`L/2` (in units of `cm`)	`L/2` (in units of `cm`)

Generate Subsystem

1 Select the Solid block and the two Rigid Transform blocks.

2 Press **Ctrl+G** to enclose the blocks in a subsystem.



3 Click the Subsystem block and press **Ctrl+M** to create a subsystem mask.

4 In the **Parameters & Dialog** tab of the Mask Editor, drag five edit boxes into the **Parameters** folder. You can find this folder in the **Dialog box** pane. In the edit fields, specify these parameters and click **OK**.

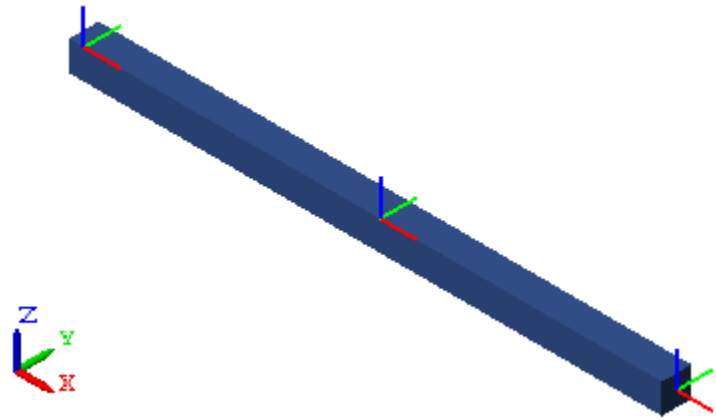
Prompt	Name
`Length (cm)`	`L`
`Width (cm)`	`W`
`Thickness (cm)`	`H`
`Density (kg/m^3)`	`rho`
`Color [R G B]`	`rgb`

5 Open the Subsystem block dialog box and specify these parameters.

Parameter	Value
Length (cm)	20
Width (cm)	1
Thickness (cm)	1
Density (cm)	2700
Color [R G B]	`[0.25 0.40 0.70]`

Visualize Model

In the model window, press **Ctrl+D**. Mechanics Explorer opens with a 3-D display of the simple link. In the Mechanics Explorer toolstrip, click the isometric view button to see the 3-D view. To view the frames present in the model, in the Mechanics Explorer menu bar, select **View > Show Frames**.



Save Model

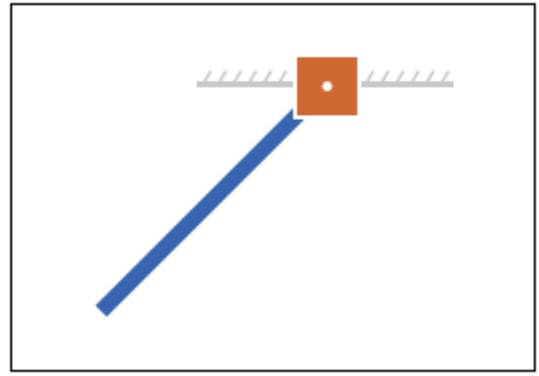
Save the link subsystem with the name Link in a custom block library. Then, see “Model Pendulum” on page 1-21 for a basic tutorial on multibody assembly using the Link block you just created.

Model Pendulum

In this section...
“Model Overview” on page 1-21
“Build Model” on page 1-22
“Specify Gravity” on page 1-23
“Add Motion Sensing” on page 1-24
“Guide Model Assembly” on page 1-24
“Assemble and Simulate Model” on page 1-25

Model Overview

The pendulum is the simplest mechanical system you can model. This system contains two rigid bodies, a link and a fixed pivot, connected by a revolute joint. In this tutorial, you model and simulate a pendulum using the custom link block you created in “Model Simple Link” on page 1-16. A Revolute Joint block provides the rotational degree of freedom between the link and the world frame.



Build Model

1 At the MATLAB command line, enter `smnew`. The SimMechanics block library and a new model open up.

2 In the model, delete all blocks except Solver Configuration, World Frame, and Mechanism Configuration.

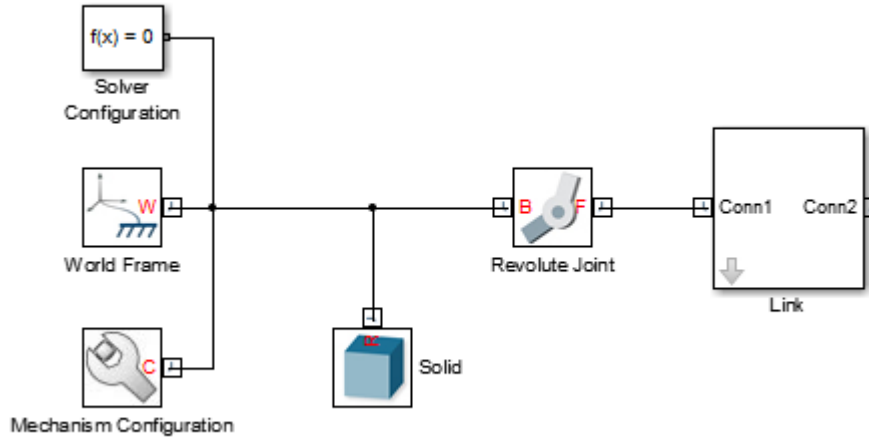
3 Drag the custom Link block into the model.

This is the block you created in the tutorial "Model Simple Link" on page 1-16.

4 Drag the following SimMechanics blocks into the model.

Library	Block
SimMechanics > Second Generation > Joints	Revolute Joint
SimMechanics > Second Generation > Body Elements	Solid

5 Connect the blocks as shown in the figure.



6 In the Solid block dialog box, specify these parameters.

Parameter	Value
Geometry > Dimensions	`[4 4 4]` (units of `cm`)
Graphic > Visual Properties > Color	`[0.80 0.45 0]`

Specify Gravity

The Revolute Joint block sets the common Z axis of its base and follower frames as the rotation axis. To ensure that gravity acts in an orthogonal direction to the rotation axis, you must change the gravity vector—by default [0 0 -9.8] m/s^2. To specify gravity so it acts along the -Y axis:

1 Double-click the Mechanism Configuration block.

2 In **Uniform Gravity > Gravity**, enter `[0 -9.81 0]` and click **OK.**.

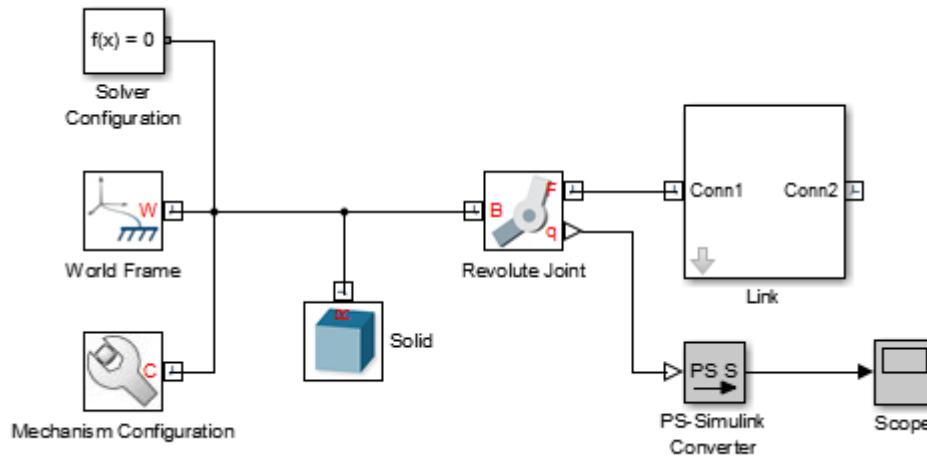
Add Motion Sensing

You can sense motion between the joint frames using the joint block. To specify the angular position of the follower frame with respect to the base frame about the common Z axis:

1. Double-click the Revolute Joint block.
2. Select **Sensing > Position** and click **OK**.
3. Drag the following blocks into the model.

Block	Library
PS-Simulink Converter	**Simscape > Utilities**
Scope	**Simulink > Sinks**

4. Connect the blocks as shown in the figure.



Guide Model Assembly

Specify the initial angle between the joint base and follower port frames:

1. Double-click the Revolute Joint block.

2 Select **State Targets > Specify Position Target**.

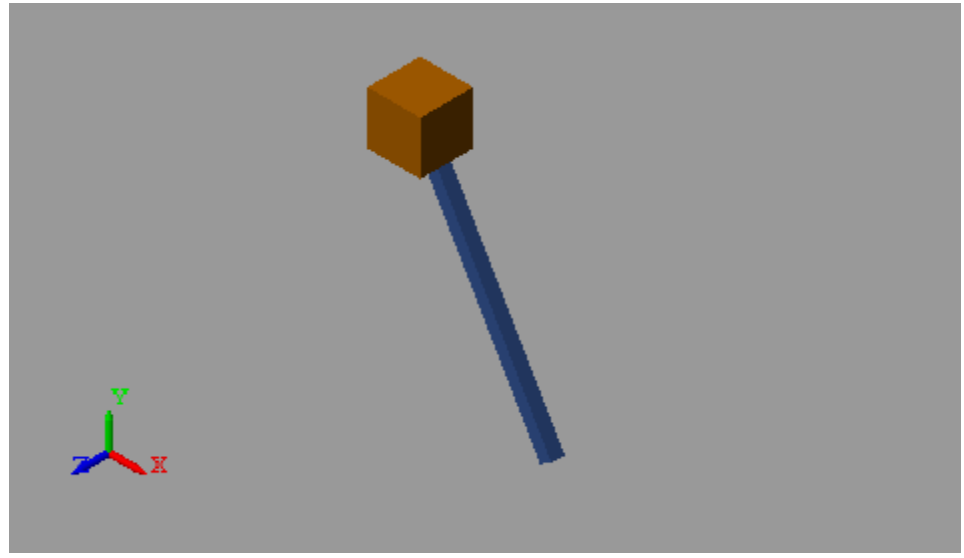
3 In **Value**, enter `-60` and click **OK**.

Assemble and Simulate Model

In the model window, press **Ctrl+D**. SimMechanics assembles the model in its initial configuration. Mechanics Explorer displays a 3-D view of this configuration with the Z axis pointing up. Since gravity acts along the -Y axis, it helps to change the view convention so the Y axis points up.

1 In Mechanics Explorer, set **View convention** to `Y up (XY Front)`.

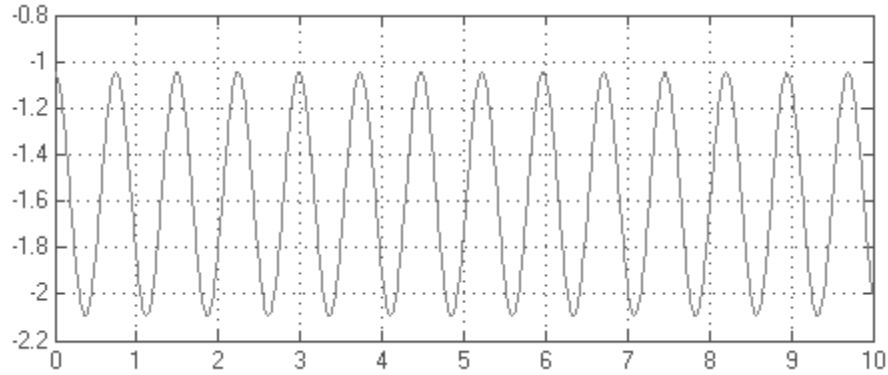
2 Click any of the view buttons to refresh the viewpoint. The figure shows the pendulum model from an isometric viewpoint.



3 Simulate the model. You can do this in the Simulink Editor menu bar by selecting **Simulation > Run**. Mechanics Explorer shows a 3-D animation of the simple pendulum.

4 Double-click the Scope block to analyze the time-varying revolute joint angle.

The figure shows the resulting plot in units of radians. Click the Autoscale button to fit the plot to the viewing area.



SimMechanics First and Second Generation Comparison

SimMechanics software contains two technologies: First Generation and Second Generation. First-generation technology includes the block library and visualization utility found in SimMechanics releases prior to R2012a. Second-generation technology introduces a simpler modeling paradigm with a new block library, a powerful computational engine, an advanced visualization utility based on OpenGL® computer graphics, and tighter integration with Simscape products.

SimMechanics first- and second-generation technologies have different sets of capabilities. Which technology to use depends on the effects you need to model. Use first-generation technology for models requiring variable gravity, certain complex constraints, or to measure reaction or constraint forces. In nearly all other cases, use second-generation technology.

The table provides a detailed comparison between first- and second-generation technologies.

Feature	SimMechanics First Generation	SimMechanics Second Generation
Mass/Inertia Calculation	Manual only	Automatic or manual
Solid Geometry	No	Yes
Animation Replay	No	Yes
3-D Model Exploration	Limited	Yes
Initial State Targets	Limited	Yes
Simscape Logging	No	Yes
Code Generation	Yes	Yes
CAD Import	Yes	Yes[1]
Motion Actuation	Yes	Yes
Force/Torque Sensing	Yes	Yes
Complex Constraints[2]	Yes	Yes[3]

Feature	SimMechanics First Generation	SimMechanics Second Generation
Variable Mass/Gravity	Yes	Yes[4]
Gravitational Fields	No	Yes

[1]CAD update supported only in SimMechanics First Generation

[2]Point-curve, Gear, Velocity, and Screw constraints

[3]Gear constraints only

[4]Variable gravity only

SimMechanics continues to support first-generation technology. You can maintain and simulate legacy models built with first-generation blocks. You also can still create a new first-generation model using the SimMechanics First Generation block library.